Optimize the Supply Air Temperature Reset Schedule for a Single-Duct VAV System

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ABSTRACT

The supply air temperature for a single-duct variable air volume (VAV) system is usually set as a constant. To minimize the simultaneous cooling and heating, this supply temperature is often reset based on either return air temperature or outside air temperature. However, resetting the supply air temperature not only impacts the cooling and heating energy consumption, but also the fan power consumption. If reset improperly, it may cause indoor air humidity problems or result in a fan power consumption penalty. This paper investigates the major factors that impact the optimal supply air temperature reset schedule which minimizes the overall heating energy, cooling energy and fan power consumption. Simulation results are compared for systems with different interior area ratios, load conditions, minimum supply airflow rates, and thermal to electrical energy price ratios.

INTRODUCTION

The supply air temperature for a single-duct VAV system is usually set as a constant. Since this constant setpoint is selected to satisfy the maximum cooling load conditions, significant reheat will occur once the airflow reaches the minimum and the heating load increases. To minimize this simultaneous cooling and heating, the supply air temperature is often reset based on either return air temperature or outside air temperature. Liu et al. (1995) reported significant energy savings by improving supply air temperature reset schedules. Liu and Claridge (1998) described the impacts of optimized cold and hot deck temperature reset schedules on dual-duct VAV systems. However, little work has been published that describes the optimal reset schedules for a single-duct VAV system. Resetting the supply air temperature not only impacts the cooling and heating energy consumption, but also the fan power consumption and the indoor air quality. If reset improperly, it may cause indoor air humidity problems or result in a fan power consumption penalty. This paper investigates the major factors that impact the optimal supply air temperature reset schedule which minimizes the overall heating, cooling and fan power consumption. Simulations are performed and the results are compared for systems with different interior area ratios, load conditions, minimum supply airflow rates, and thermal to electrical energy price ratios. HVAC system operators and commissioning engineers should keep these factors in mind when they develop the reset schedules for the supply air temperature in single-duct VAV systems.

METHODOLOGY

To simplify the analysis, consider a VAV system with both interior and exterior areas. The load condition for the interior area is relatively stable throughout the year. However, the load varies greatly with the ambient conditions for the exterior area, which experiences maximum cooling load in the summer and maximum heating load in the winter. During the cooling season, the supply air temperature is usually kept at a relatively low constant set point (for example, 55°F) and the air handling unit (AHU) varies the total supply airflow rate to satisfy the cooling load. During the heating season, the exterior area is in the heating mode while the interior area still requires cooling. The relatively constant interior cooling load can be satisfied in two ways: Supply low temperature air with a low airflow rate that is not less than the minimum flow requirement, or supply higher temperature air with a higher airflow rate. The first option lowers the fan power consumption while increasing the exterior zone reheat energy consumption. The second option increases the fan power consumption but reduces the exterior zone reheat energy consumption. The optimal supply air temperature schedule should balance the thermal and electrical energy costs to achieve the minimum total operating costs.

Total energy consumption cost (thermal energy and fan power) is a function of the price ratio of thermal to electrical energy, relative size of interior cooling load and exterior heating load, and type of air volume control — variable frequency drive (VFD) or inlet guide vanes (IGVs). To find the optimal supply air temperature reset schedule under different conditions, total energy consumption cost is simulated using a program called "AirModel" (Liu 1997). The bin weather data (Degelman 1984) for San Antonio, Texas is used in the simulation. The median of each 5°F bin is used as the average temperature, and the weighted average of the coincident wet bulb temperatures is used as the average wet bulb temperature. Figure 1 shows the annual average dry bulb and wet bulb temperature for San Antonio, Texas.

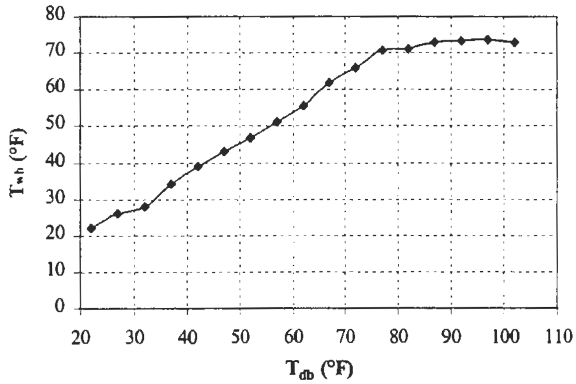

Figure 1. Annual average dry bulb and wet bulb temperatures for San Antonio, Texas.

A pseudo building with one VAV AHU and two zones – one interior zone and one exterior zone, is modeled with the simulation program. Key building and AHU parameters are as follows:

- The building is 200 ft long, 100 ft wide, and 3 stories high (60,000 ft^2)
- Internal load is 1.5 W/ft^2
- U value for exterior windows is 0.65 Btu/hr-ft^2-°F
- U value for exterior walls is 0.1 Btu/hr-ft^2
- Maximum supply air flow rate is 1.0 cfm/ft^2
- Minimum air flow rate is 0.3 cfm/ft^2
- Minimum outside air flow rate is 0.1 cfm/ft^2
- Supply air temperature is maintained at 55°F constant under normal operation
- A VFD is used to modulate the fan speed

Simulations are performed for systems with different interior area ratios, load conditions, minimum supply airflow rates, and price ratios of thermal to electrical energy.

SIMULATION RESULTS AND DISCUSSION

To demonstrate the potential energy and cost savings from optimizing the supply air temperature, building operating costs are compared under the normal operation schedule and the optimal reset schedule. It is assumed that the interior area ratio is 50%. The normal operating schedule uses a constant supply air temperature set point of 55°F. Simulation is performed and the optimal supply air temperature schedule is identified, as shown in Figure 2. It is assumed that the cooling coil can provide 54°F supply air.

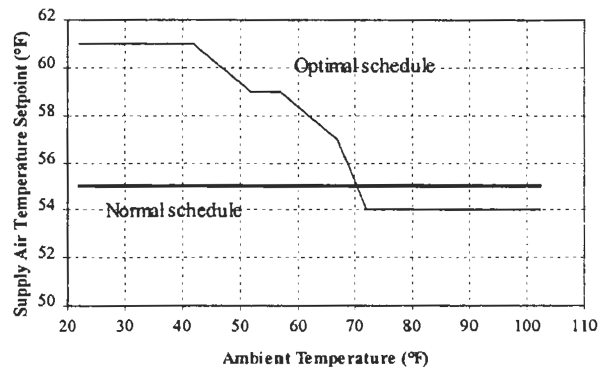

Figure 2. Comparison of normal supply air temperature schedule and optimal supply air temperature schedule.

Annual energy consumption and operating costs are summarized in Table 1. It is assumed that the chilled water price is $3.25/MMBtu, the hot water price is $3.45/MMBtu, and the electrical price is $0.04/kWh.

Table 1. Comparison of energy consumption and operating costs under normal supply air temperature schedule and optimized schedule.

Supply Air Temp.	Chilled Water MMBtu	Hot Water MMBtu	Fan Power (kWh)	Total Costs ($)
55°F	4,884	549	116,383	22,424
Optimal	4,689	411	114,177	21,224
Reduction	4%	25%	2%	5%

It can be seen that by optimizing the supply air temperature reset schedule, the largest percentage savings come from the hot water consumption reduction for this case. However, a number of factors can greatly influence the optimal supply air temperature reset schedule. Some key parameters that can impact the optimal schedules, such as the building interior area, the internal heat gain, minimum supply airflow rates, and the price ratios of the thermal energy to electrical energy, are examined here.

To investigate the impact of the interior area ratio on optimal reset schedule, simulations are performed for the building by using different interior area ratios. Figure 3 presents the optimal supply air temperature reset schedule for a VAV system with interior area ratios of 30% and 70%, respectively. With an internal heat gain rate of 1.5 W/ft^2, and a price ratio (defined as \$/MMBtu divided by \$/100kWh) of 0.86 between heating water and electrical power. The graph shows that the supply air temperature can be reset more aggressively under the same ambient temperature when the interior area ratio is larger.

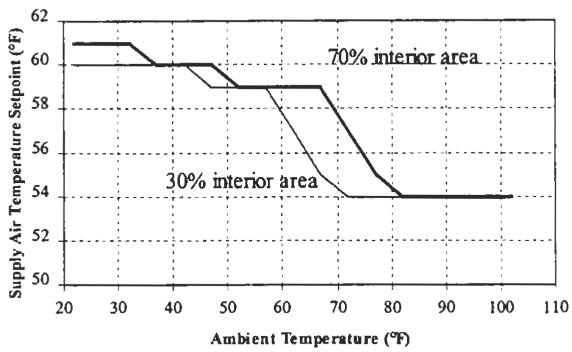

Figure 3. Comparison of optimal supply air temperature schedules for systems with different interior area ratios (internal heat gain is 1.5 W/ft^2 and price ratio is 0.86).

The impact of the price ratio of thermal to electrical energy is investigated next. The price ratio is increased from 0.86 to 1.5 while the internal heat gain is kept unchanged. Simulations are performed and the optimal reset schedule is identified in Figure 4. It can be seen that optimal reset schedule now has a steeper slope for systems with smaller interior area.

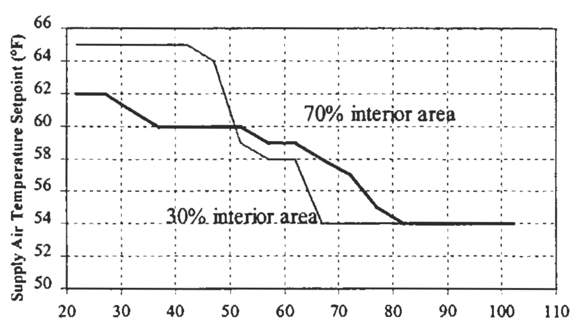

Figure 4. Comparison of optimal supply air temperature schedules for systems with different interior area ratios (internal heat gain is 1.5 W/ft^2 and price ratio is 1.5).

The next simulation examines the impact of internal heat load level. The internal heat gain is increased from 1.5 W/ft^2 to 2.3 W/ft^2 while keeping the price ratio of heating to electrical unchanged. The difference in interior area ratio now plays a major role in optimal reset schedule, as shown in Figure 5. The system with less interior areas now has a more aggressive reset schedule since the penalty associated with providing more flow to the interior area is outweighed by the savings resulting from less reheat in the exterior area.

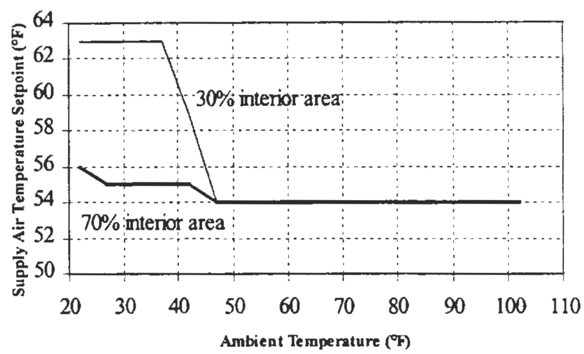

Figure 5. Comparison of optimal supply air temperature schedules for systems with different interior area ratios (internal heat gain is 2.3 W/ft^2 and price ratio is 0.86).

The same relationship is true when the price ratio changes. Figure 6 shows the optimal reset schedules for the two systems when the price ratio changes. Note that the supply air temperature should now be reset higher during the heating season since reheat is becoming more costly.

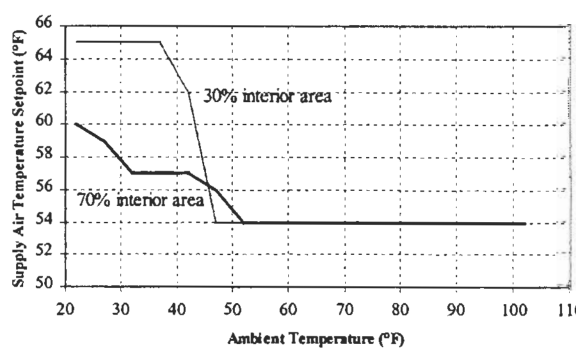

Figure 6. Comparison of optimal supply air temperature schedules for systems with different interior area ratios (internal heat gain is 2.3 W/ft^2 and price ratio is 1.5).

The minimum supply airflow rate also impacts the optimal supply air temperature schedule. When the internal heat gain is kept at 2.3 W/ft^2 and the price ratio of heating to electrical remains unchanged at 1.5, optimal supply air temperature schedules are obtained while the minimum total supply airflow rate increases from 0.3 cfm/ft^2 to 0.4 cfm/ft^2. Figure 7 below shows the optimal schedules for the two systems with an increased minimum airflow rate. It can be seen that the optimal supply air temperature increases during mild conditions for both cases.

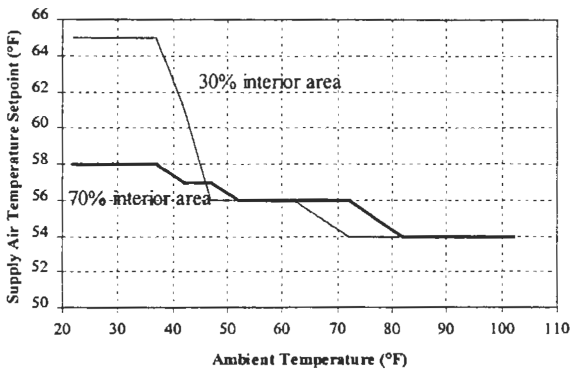

Figure 7. Comparison of optimal supply air temperature schedules for systems with different interior area ratios under increased minimum airflow (internal heat gain is 2.3 W/ft^2 and price ratio is 1.5).

CONCLUSIONS

This paper demonstrates that substantial energy savings can be achieved in a single-duct VAV system if the supply air temperature is reset properly. However, the optimal reset schedule is greatly influenced by system parameters such as the interior area ratio, the amount of internal heat gain, minimum supply airflow rate, and the price ratio of heating energy to electrical power, etc. The influence of those parameters on optimal supply air temperature reset schedules has been briefly evaluated in this paper. System operators should keep these factors in mind when they develop the optimal supply air temperature reset schedules.

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